

# Electrochemical Tuning and Investigations on Actuator Mechanism of Single-Wall Carbon Nanotubes

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## Abstract

The isothermal conversion of chemical energy into mechanical work underlies the motility of all living systems - *natural muscles*. In this presentation, actuators built from a macro scale sheets of single-wall carbon nanotubes (*bucky paper*), which is among the growing list of several actuator materials since its pioneer demonstration, will be investigated. They are therefore dubbed as *artificial muscles* lying under the category of electro-chemo-mechanical devices, whereby the transformation of chemical energy into mechanical energy is triggered by electrical signal or dc bias [1]. They operate as a result of double-layer (*i.e.* electrochemical double layer; ECDL) charge injection in electrodes having very high gravimetric surface area and gravimetric/specific capacitance and the output of the actuator may be a mechanical displacement that can be used to accomplish mechanical work. Despite several benefits (low operating voltages, conducting nature, high temperature performance, and unusual electro-mechanical coupling), some open questions concerning the actuation principle/mechanism remain. They stretch if they are electrically charged and stretching is due to the elongation of C-C bond (*i.e.* tangential displacement mode) - if bonding states are depopulated or if anti-bonding states are populated.

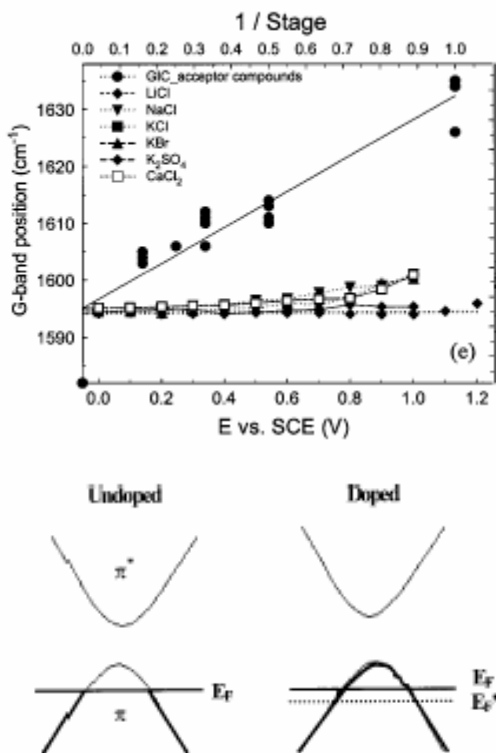
This study addresses and presents these issues and aim to comprehend the various contributions by investigating the charge transfer dynamics on the surface of single-wall carbon nanotubes using *in situ* resonance Raman spectroscopy (RRS) and to determine the associated parameters include microscopic strain, fractional charge transfer and the corresponding shift in Fermi level through modeling [2, 3]. We found the in-plane compressive strain ( $\sim -0.25\%$ ) and the charge transfer per carbon atom ( $f_c \sim -0.005$ ) as an upper bound for the electrolytes used *i.e.*  $\text{CaCl}_2$  (see Fig. 1). These results can be quantitatively understood in terms of the changes in the energy gaps between the one-dimensional van Hove singularities in the electron density of states arising possibly due to the alterations in the overlap integral of  $\pi$  bonds between the p orbitals of the adjacent carbon atoms. Moreover, the extent of variation of the absolute potential of the Fermi level or alternatively modification of band gap is estimated from modeling Raman intensity to be around 0.1 eV as an upper bound for  $\text{CaCl}_2$ . The cyclic voltammetry (see Fig. 2) and ac electrochemical impedance spectroscopy results will be discussed briefly which help to demonstrate well-developed capacitive behavior of single-wall carbon nanotubes sheet and to estimate the gravimetric/specific capacitances as well.

## References

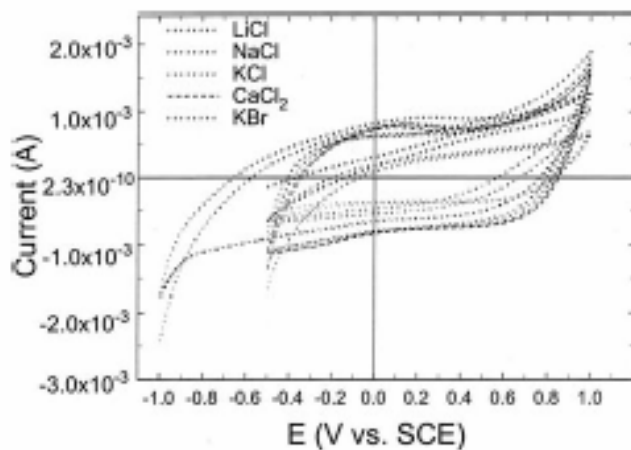
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**Figure 1.** (top) Variation of *G* band vs. electrochemical potential relative to reference electrode (SCE) for all of the aqueous electrolytes: LiCl, NaCl, KCl, KBr, K<sub>2</sub>SO<sub>4</sub>, and CaCl<sub>2</sub>. The variation of *G* band for several GIC-acceptor compounds from is also provided for comparison. (bottom) Schematic of suggested energy-level band diagram corresponding to (top) demonstrating the tuning of electronic structure of SWNTs due to electrochemical charge transfer.



**Figure 2.** Shown are the cyclic voltammograms for all of the aqueous electrolytes scan rate, 50 mV/s from -0.5 to 0.1 V vs. SCE. The CV curve for one of the electrolytes; LiCl for a full potential cycle from -1.0 to 1.0V is also provided. All of the electrolytes are of 0.1 M concentrations.